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In vivo depth heterogeneity of the abdomen assessed by broadband time-domain diffuse optical spectroscopy

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ABSTRACT

We investigated depth heterogeneity in the abdomen using time-domain diffuse optical spectroscopy at 3 source-detector distances, finding a higher water content in shallower regions, possibly ascribed to fat heterogeneity and/or skin contributions.

Keywords: Diffuse Optics; Spectroscopy, tissue diagnostics; Tissue characterization; Lipids; Absorption; Scattering

1. INTRODUCTION

Obesity, metabolic diseases, food- and lifestyle-related morbidities are key challenges of the growing and aging society. Recently, the role of fat tissue in the onset and progression of these diseases started to be addressed [1,2]. Diffuse optical spectroscopy could provide a valuable tool for monitoring non-invasively fat-related changes induced by disorders, treatments or simply lifestyle habits. In particular, Diffuse Optical Spectroscopic Imaging (DOSI) was demonstrated to provide spectral images of the fat tissue of volunteers undergoing calorie restriction [3]. Increased water and blood content was observed together with scattering alterations following a 12-week diet period.

In this paper, we explore the use of Time-domain broadband Diffuse Optical Spectroscopy (TDOS) for the non-invasive in vivo characterisation of subcutaneous fat tissue. In particular, we performed multidistance time-resolved measurements to investigate the layered nature of the abdomen, and its effects on the recovered absorption spectra. Our aim is to build some basic knowledge on the effect of probe geometry, location and acquisition on the spectral information gained from the abdomen tissue so to set a first ground for an upcoming clinical study.

To this end, a portable clinical prototype for TDOS [4], already applied in clinical studies [5], was used to recover the absorption and reduced scattering spectra of the abdomen on healthy volunteers at different source-detector distances.

2. METHODS

2.1 Instrumentation

A schematic diagram and a photo of the clinical prototype is depicted in Fig. 1. The source is provided by a supercontinuum fibre laser (SC450, Fianium,UK) with 6 W overall power over the spectral range 450-1750 nm. The pulses of few picoseconds width are generated at a 40 MHz repetition rate. Spectral tunability is achieved by dispersing the source with a Pellin-Broca prism and coupling the selected wavelength into an optical fiber. To achieve higher responsivity, two different detectors, a Silicon Photomultiplier (SiPM) [6,7] and Hamamatsu InGaAs PMT, are used to cover a wide spectral region. A pellicle beam splitter is used to change detector at desired wavelength. The system was designed to work efficiently over the range of 600-1200 nm. A reference path allows us to acquire the instrument response function (IRF) in the same time window as the signal to compensate for shape distortion in real time in a clinical environment. The probe consists of a 3D printed flexible holder securing the 1 mm core injection and collection fibres at a given interfibre distance ρ onto the tissue in reflectance geometry. A thin layer of black foam was attached beneath the holder to capture unwanted directly reflected or sneaky light from the tissue surface. The fibre probe was hold in place using an articulated rod support.

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2.2 Data Analysis

The photon temporal distributions were analysed using a Levenberg-Marquard algorithm by convolving the IRF with the solution of the Diffusion equation under the extrapolated boundary conditions for a homogeneous medium. The whole analysis can be performed automatically in real time while the measurement is in progress.

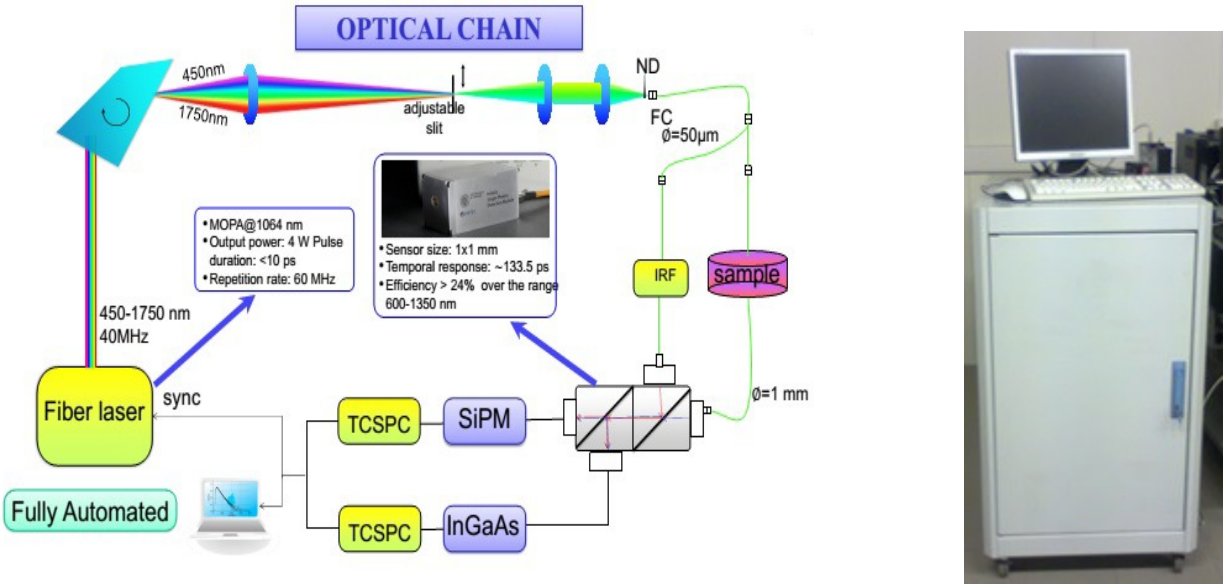

Figure 1. Layout of the clinical prototype (left) and photo of the instrument (right).

2.3 in vivo Study

Up to now, 3 male volunteers were enrolled in the study, as summarised in Table 1, where "Thickness" is referred to the subcutaneous adipose layer thickness. Two positions on the abdomen were assessed at horizontal distances of 4 and 8 cm from the navel (Position 1 and Position 2, respectively), with the subject lying supine. For each position, spectra were taken at ρ = 1, 2, and 3 cm, spanning the 600-1100 nm range in steps of 10 nm. At each wavelength, 4 repetitions of 1 second each were acquired. Informed written consent was obtained from all subjects prior to the study.

Table 1 – Demographics of the subjects involved in the study.

Subject	Age (y)	Height (cm)	Weight (kg)	BMI (kg/m^3)	Thickness1 (cm)	Thickness2 (cm)
#1	50	175	82	26.8	2.3	1.8
#2	44	184	100	30.0	2.3	1.9
#3	72	174	66	21.8	1.2	0.8

3. RESULTS AND DISCUSSION

Figure 2 shows the recovered absorption spectra for the 3 subjects (rows) at the 2 positions on the abdomen (columns) for the 3 source-detector distances. In almost all cases a significant increase in absorption above 950 nm is observed for the shortest distance (ρ = 1 cm). This is a clear indication of a higher water content that yields a major absorption peak around 970 nm. In some cases (e.g. first two rows, right column) we observe also an increase at lower wavelengths, compatible with a higher blood content. Since these higher values are observed for the lowest ρ, they can be ascribed to shallower

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regions. For the last subject – the one with the lowest fat thickness – there is an increase in absorption below 900 nm in the blood absorption region, possible indicating some contamination from the muscle. All these trends as a function of ρ are confirmed also when the fitting range is shifted towards early (i.e. more superficial) or late (i.e. deeper) photons.

Based on the measured optical properties (absorption and scattering) of the abdomen tissue, and the temporal range of the fit, it is possible to infer the maximum depth reached on average by photon trajectories inside the tissue [8]. Typically, for the region around 930 nm (maximum absorption due to the lipid peak) we obtain a maximum depth around 1, 1,4, and 1,6 cm for ρ = 1, 2, and 3 cm, respectively, and larger values beyond 950 nm. A first obvious explanation for the increased absorption could be the contribution arising from the dermis, which is typically highly hydrated. Yet, its thickness does not exceed few mm, thus it could contribute marginally even at the shortest ρ. Another explanation could be an uneven composition in depth of the adipose tissue itself, possibly richer in water in subcutaneous regions.

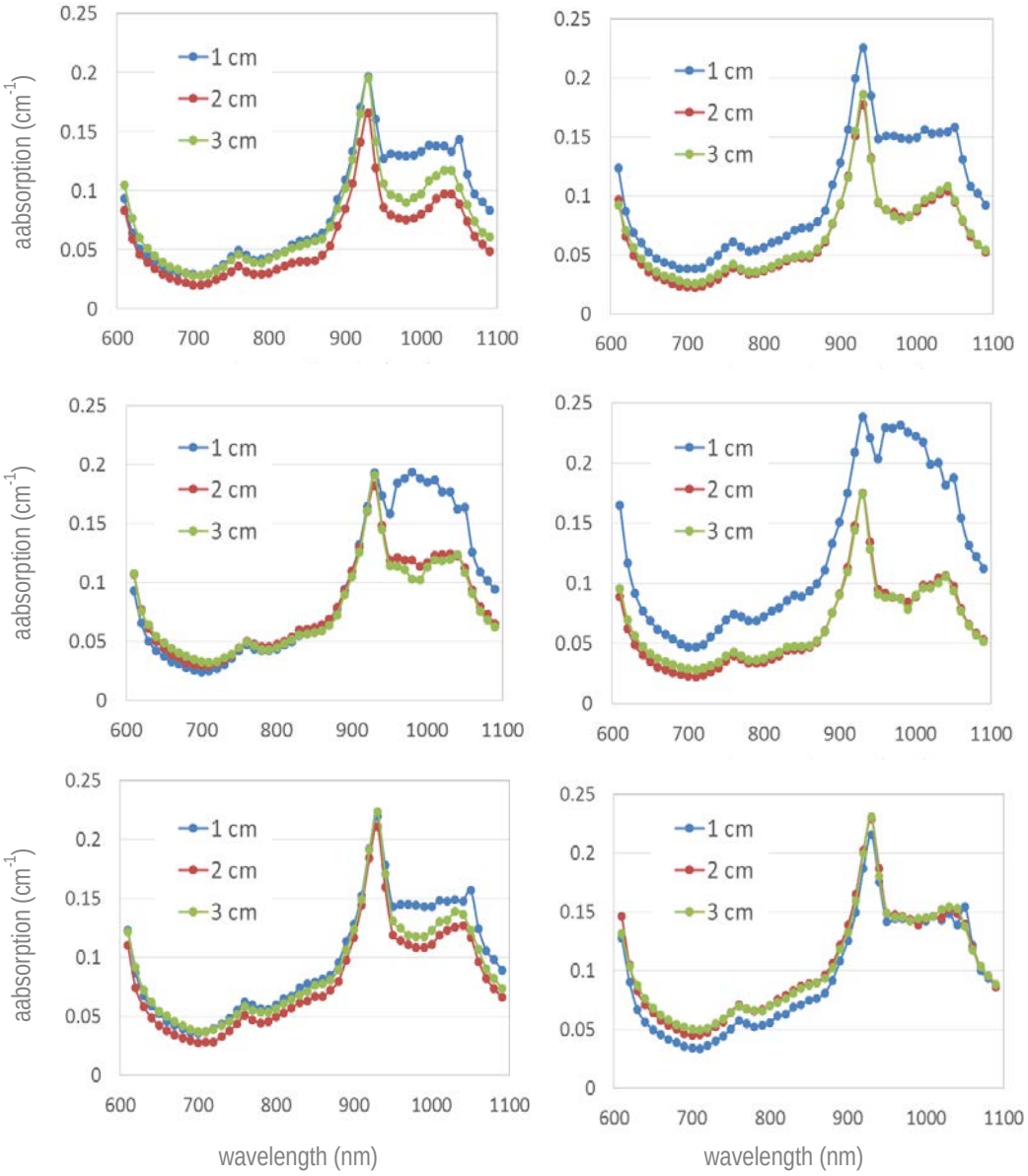

Figure 2. Absorption spectra for the 3 subjects (rows) at position 1 (left) and 2 (right) for the 3 source-detector distances.

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4. CONCLUSIONS

In conclusion, we have investigated the depth heterogeneity on the human abdomen by time-domain broadband diffuse optical spectroscopy. Using multidistance measurements, it is possible to identify a shallower region richer in water and blood. In view of an upcoming clinical study, it is interesting to ascertain whether this contribution arises from the adipose tissue itself – and thus is a potential indicator of fat tissue metabolism – or rather is an unwanted contamination from the superficial dermis, to be carefully controlled in fat tissue monitoring. Further studies are certainly needed to understand the best approach to monitor physiology and pathology of the adipose fat organ. Still, as future perspectives, the introduction of new photonics devices open the way to deployment of compact and wearable health appliances for personal monitoring [9-12].

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